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Implications of Global Climate Change for Western Agriculture

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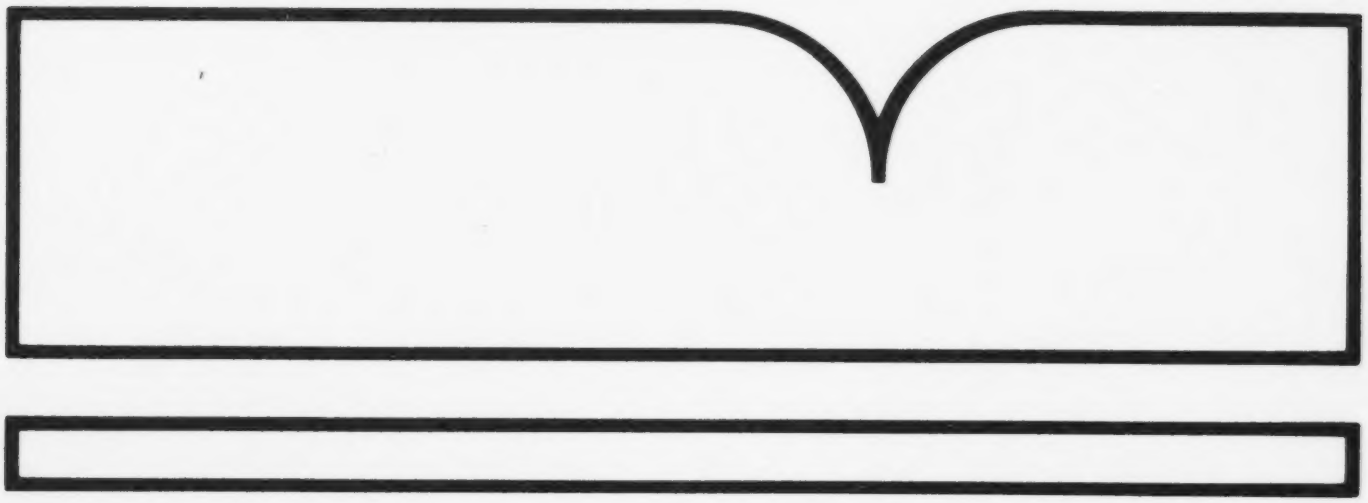

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Implications of Global Climate Change for Western Agriculture

R. M. Adams, B. A. McCarl, D. J. Dudek, and J. D. Glyer

Global climate change from increases in atmospheric carbon dioxide and other trace gases is an issue of international concern. Adverse climatic conditions are expected to reduce crop yields and alter the demand for and supply of water. These potential adjustments imply economic costs to agriculture and its constituents. This paper explores possible economic implications for U.S. agriculture, with particular reference to the West. Results from a series of spatial equilibrium model analyses suggest that climate change is not a food security issue for the United States. However, regional adjustments in agricultural production and associated resource use are expected. This implies additional pressure in rural communities. Environmental quality reductions are also likely.

Key words: agriculture, climate change, economic effects.

Global climate change arising from increases in atmospheric carbon dioxide (CO_2) and other trace gases, such as chlorofluorocarbons (CFCs) is an issue of international concern. While the rate of future atmospheric CO_2 increases is uncertain, CO_2 is currently increasing at four to five parts per million (ppm) per year (Ramanathan). If this trend continues, as some predict, it portends dramatic changes in climatic conditions beyond any observed in historical times. Furthermore, some scientists contend that accumulations to date imply climatic changes even if CO_2 emissions are curtailed. Spatial and temporal variability of climatic patterns are also expected to be greatly increased (Rind, Goldberg, and Ruedy).

The implications of CO_2-induced climate changes are complex, occurring on a truly global scale with potential effects on virtually all ecosystems (Wigley, Ingram, and Farmer). One ecosystem of particular importance to human welfare is agriculture. The consequences of crop failure arising from unfavorable climate are apparent, as exemplified by the ongoing drought-induced famine in the Sahel region of Northern Africa. While the large geographical area and technological base of U.S. agriculture make massive crop failures due to climate change unlikely, regional adjustments in crop production and resource use may result.

The potential agricultural effects of global climate change are discussed in qualitative terms in numerous studies (Decker, Jones, and Achutuni; Rosenzweig 1986; Callaway et al.). For example, Rosenzweig (1986) identified the following consequences for agricultural productivity: (*a*) changes in yield due to increased atmospheric CO_2 concentration, changes in temperature and precipitation patterns, and the likelihood of increased pest and pathogen populations arising from a warmer global climate; and (*b*) adjustments in irrigation water demand and supplies. This second category of effects is of particular importance to the west-

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ern United States. In combination, these factors may alter crop yields and agricultural production patterns, which in turn imply a range of secondary effects, such as changes in resource usage with attendant effects on input suppliers, environmental quality, and the structure of rural communities.

Objectives

The purpose of this paper is to explore possible economic implications of climate change for western irrigated agriculture. These implications are drawn from two recent studies that address the economic effects of CO_2-induced climate change on the agricultural sector (Adams, Glyer, and McCarl; Dudek). Both studies use mathematical programming-based models to estimate the effects of a doubling of CO_2; Adams, Glyer, and McCarl examine implications in the major U.S. production regions, while Dudek examines such effects in California. Together, these assessments identify a range of physical and economic effects that have implications for the western United States.

A note of caution is in order before proceeding. The time horizon for a possible doubling of atmospheric CO_2 and its associated effects is uncertain, perhaps up to seventy-five years or more. Forecasting biologic, economic, or any other events over such a long time period is a difficult task. Given that this analysis is based on both uncertain biologic and economic forecasts, the results and implications reported here should be viewed only as suggestive of potential effects of climate change on agriculture.

Background and Data

An economic assessment of environmental change requires input from several disciplines. In this case, the starting point is definition of likely increases in atmospheric CO_2. Current projections suggest that atmospheric CO_2 may double from current levels (of about 300 ppm) over the next fifty to seventy-five years (Ramanathan). This buildup is primarily the result of past and present rates of fossil fuel combustion. According to the "greenhouse" theory of climate change, such increases in CO_2 (a radiatively active gas) and related trace gases are expected to result in more heat trapped in the troposphere (lower atmosphere). This additional heat in turn alters global atmospheric and oceanic circulation patterns, triggering a range of climatic changes as the climate system establishes a new equilibrium.

The central question here is what this new equilibrium means in terms of changes in temperature, precipitation, and other climatic variables across agricultural production regions. Two sets of climate change models are used to provide this information: the Goddard Institute of Space Studies (GISS) and the Princeton University Geophysical Fluid Dynamics Laboratory (GFDL) global climate models. Each model forecasts changes in regional temperature, precipitation, evapotranspiration, and other climate variables associated with changes in CO_2.

Forecasts of expected annual and seasonal temperature and precipitation changes in the United States from each model are summarized in table 1. In addition, forecasts from an Oregon State University climate model are also presented. All three models predict dramatic increases in annual average temperature (of 4–5 degrees celsius, or up to about 9° Fahrenheit) resulting from a doubling of CO_2. Annual precipitation is predicted to increase as well, but with greater seasonal variation (Rind, Goldberg, and Ruedy). Such an increase in the earth's temperature over so short a time period would be unprecedented (Ramanathan) and would have implications for plant growth, water demand, groundwater recharge, snow pack, streamflow, and other factors affecting agriculture.

Table 2 presents selected regional forecasts of temperature, precipitation, and evaporation for the GISS and GFDL models, expressed as ratios relative to the 1951–80 time period. All regions of the United States are warmer, some slightly more so than others. A slight increase in rainfall is expected in most regions, but it is not sufficient to offset expected increased crop evapotranspiration. The GFDL projections present a more severe set of climatic changes for agriculture, forecasting a warmer and dryer climate than GISS. Both models predict that a few areas, such as the Northwest, California, and northern Rocky Mountains, may have more total runoff. Details of these hydrologic changes are presented in Adams, Glyer, and McCarl, and Dudek.

Table 1. Summary of Three Climate Model Change Projections for 2 × CO_2: Average of U.S. Grid Points

Model	Temperature Change			Precipitation Change		
	Annual	Winter	Summer	Annual	Winter	Summer
	(degrees celsius)			(mm/day)		
Goddard Institute for Space Studies (GISS)	+4.32	+5.46	+3.50	+0.20	+0.13	+0.24
Geophysical Fluid Dynamics Laboratory (GFDL)	+5.09	+5.25	+4.95	+0.09	+0.19	−0.08
Oregon State University (OSU)	+2.98	+2.95	+3.10	+0.17	+0.24	+0.11

Crop Yield Effects

The climate changes described in tables 1 and 2 are expected to lead to changes in crop yields. The effects of these climate changes on irrigated and dryland yields of wheat, corn, and soybeans have been estimated by plant scientists at Goddard NASA's Space Flight Center Institute for Space Studies, University of Florida, and Michigan State University, using the CERES family of crop growth simulation models (Ritchie and Otter). For cotton and other nonmodeled crops, responses from the model predictions for corn, wheat, and soybeans were averaged to develop surrogate responses.

For most crops in most places, the simulations indicate lower yields under the forecast climate conditions, with the GFDL climate projections resulting in substantially lower yields than GISS. Specifically, the GISS climate changes result in yield losses for dryland production of about 15%–20% from 1981–83 levels; for GFDL dryland yield losses approach 70% in some regions. In general, yield reductions are greater in the more southerly latitudes of the United States. For example, soybean yields actually show a slight increase in more northerly latitudes, such as the Lake States. Yield reductions for irrigated production are generally much less than for dryland crops. This differential has important implications for the western United States, as discussed subsequently.

Additional crop-yield adjustment simulations were performed which allowed for a direct yield enhancing CO_2 effect (increases in CO_2 increase plant growth, *ceteris paribus*). This served to moderate or even offset the adverse yield effects of climatic change. Also, none of the yield forecasts reflect changes in genetic engineering and other forms of biotechnology that could make plants more suitable to new climate regions. Crop yield projections and associated standard deviations for various locations, along with details of the yield simulation procedures, are reported in studies by Rosenzweig 1988; Peart et al.; and Ritchie, Baer, and Chou.

Table 2. Climatic Characteristics of Nine Agricultural Regions as Predicted by GISS and GFDL Models Under the 2 × CO_2 Scenario

	Evaporation Ratio		Precipitation Ratio		Average Annual Temperature Increase, °C	
	GISS	GFDL	GISS	GFDL	GISS	GFDL
Northwest	1.166	1.099	1.23	1.027	4.4	4.5
California	1.069	0.970	1.062	1.018	4.9	4.9
Northern Mountains	1.151	1.097	1.18	1.017	4.8	5.5
Southern Mountains	1.062	1.031	1.05	0.986	4.9	5.1
Northern Plains	1.085	0.989	1.07	0.966	4.7	5.9
Southern Plains	0.985	1.018	0.922	0.997	4.4	4.5
Delta	1.024	1.016	1.024	1.003	5.3	4.4
Southeast	1.084	0.927	1.105	0.922	3.5	4.9

Hydrologic Effects

In addition to altering crop yields, changes in temperature and precipitation will affect crop water requirements and water supply. Forecasts of crop water requirements and availability are thus an important aspect of the analyses reported here. These forecasts are developed using regional total precipitation and evaporation estimates from the GISS and GFDL models.

Development of such water demand and supply forecasts from the climate models requires numerous assumptions. For example, the climate models have differing degrees of spatial resolution (12 grid points for GISS, 19 for GFDL for the U.S.). For most regions, there are only one or two grid boxes with which to predict regional climate changes. It is assumed that the climatic values as estimated for these few grid points adequately represent the region in which they fall. For each grid point, both baseline and 2 × CO_2 values for each climate variable (e.g., temperature) are estimated. The ratio of the 2 × CO_2 estimate to baseline then provides an indication of the percent change in that particular variable. Mappings of the GISS and GFDL grid points and other details are provided in Adams, Glyer, and McCarl.

Regional crop water requirement changes are estimated based on evaporation and precipitation changes forecast by the climate models. Specifically, the ratio of percent changes in evaporation and rainfall were calculated by region to arrive at a net change in crop water requirements. Thus, if evaporation is forecast to increase more than local rainfall, crop water requirements (evapotranspiration less rainfall) are expected to increase. The data on which the regional calculations are based are summarized in table 2. These changes in water requirements then alter the demand for water in the economic models. Specifically, in the national assessment, cropping patterns, crop acreages, and crop water requirements were the primary determinants of regional irrigation demand. Alternative irrigation management systems were added in the California model.

Forecasts of available irrigation water (ground and surface) also reflect the interaction of evaporation and rainfall. If changes in expected rainfall are greater than long-term mean evaporation, some "surplus" should result, with increased runoff and hence greater irrigation water supplies. The ratio of net change in potential run-off was used in the national assessment to adjust baseline water availability levels for each irrigated region. For surface water, it is assumed that irrigation is a "senior" (and over-subscribed) water right within the applicable water doctrine for each state. Therefore, any increases in streamflow will be allocated to irrigation. Also, in the national assessment it was assumed that reservoir management will adjust to new climatic and streamflow regimes, thus storing water earlier in the winter runoff period.

In the California case study, more detailed hydrologic analyses for the Central Valley were developed. Rainfall-runoff simulations using the 1951–80 historic variability were conducted using the GISS and GFDL climate model forecasts (Lettenmaier). These simulated flows were then translated into surface water deliveries to project service areas using a temporal routing model of the joint operations of the federal Central Valley Project (CVP) and the State Water Project (SWP) (Sheer and Randall). In California, changes in the operating rules for reservoirs did not mitigate the effects of a shift in precipitation from snow to rain as a result of temperature increases. Snowmelt storage was lost and increased winter flows were released in order to maintain flood control capacity.

Economic Modeling Procedures

The exogenously estimated regional yield and water resource changes associated with each climate model are introduced into the economic models through modifications in (*a*) regional crop yields, (*b*) crop water use coefficients, and (*c*) regional water supply levels. The subsequent model runs then translate the physical and biological effects into economic consequences, including shifts in regional market shares (i.e., comparative advantage), changes in producers' returns, changes in consumers' well-being, and other economic aspects.

The economic model used to capture these effects across U.S. production regions represents production and consumption of thirty-six crop and livestock commodities (Adams, Hamilton, and McCarl). The production and consumption sectors are assumed to be made up of a large number of individuals, each of whom operates under competitive market

conditions. Producer-level behavior is captured in technical coefficients that portray the physical and economic environment in each of the sixty-three production regions in the model, encompassing the forty-eight contiguous states. These regions are then aggregated to ten macro-regions defined by USDA. Of importance here is the inclusion of both irrigated and nonirrigated crop production and water supply relationships for each region. Both surface and groundwater are modeled; per unit costs of surface water are fixed, but groundwater supplies are available at increasing costs. Resource availability, including surface irrigation water, is defined at the regional level. Farm-level supply responses generated from the sixty-three regions are linked to national demand through the objective function which features demand relationships for various market outlets for the included commodities. This leads to a model which maximizes the area under the demand curves less the area under the supply curves (sum of ordinary consumers' and producers' surplus) or net social benefit. Both domestic and foreign consumption (exports) are considered. The assumptions and analytics of the model are discussed in more detail in Adams, Hamilton, and McCarl; and McCarl and Spreen. The model simulates a long-run, perfectly competitive equilibrium as reflected in 1981–83 economic and environmental parameters.

For the California case study, a separate mathematical programming model (The California Agricultural Resources Model, or CARM) of similar conceptual design was employed. Production possibilities were defined by seven homogenous production regions with sixteen principal crop commodities and seven alternative irrigation systems. Demand relationships represented in the model specifically account for California's participation in national and international markets. CARM is described in detail in Adams, King, and Johnston; Howitt and Mean; and Dudek.

Results

The two climate models give rise to two distinct sets of crop yield and hydrologic assumptions. In addition, assumptions concerning future technology, the effects of CO_2 on crop yields, demand, and other uncertainties were also analyzed. As a result, a number of solutions were generated with the economic models. Each change in crop yields, water availability and other assumptions gives rise to changes in economic measures (e.g., economic surplus, land use, irrigated acreage, water, and other inputs) compared with the baseline case for each economic model. The direction and magnitude of these changes across the economic models indicates the potential importance of adjustments in response to underlying climate change.

The diverse set of assumptions explored in these analyses (different climate models, different crop and water assumptions, different technology and demand assumptions) provides a set of results that can tell many stories. This section interprets those results with respect to common themes or implications. For perspective, we start with some general findings concerning national level effects. We then focus on regional effects and specific water resources implications for the western United States. We conclude with implications for other resources and future research needs.

Aggregate Economic Effects

Not surprisingly, estimates of the economic consequences of climate change are sensitive to the climate model projections. This can be seen in table 3, where annual aggregate losses in social welfare (in the absence of technology or CO_2-yield-enhancing effects) range from \$6 billion (1982 dollars) for the GISS climate forecasts to over \$33 billion for the GFDL model. These estimates are from about 5% to 28% of the 1982 value of U.S. crop and livestock commodities. On a per capita basis, the domestic economic surplus losses are \$6 and \$65 per U.S. citizen for the GISS and GFDL models, respectively. The larger GFDL-based losses are driven by potential declines in production of some crops of up to 50%. For California alone, climate change impacts for GFDL total roughly \$2 billion (1985 dollars).

These economic surplus estimates can also be compared to economic effects of other environmental stresses. For example, the economic consequences of tropospheric ozone on U.S. agriculture are estimated to be about \$2 to \$3 billion per year in 1982 dollars (Adams, Hamilton, and McCarl). Similarly, estimated effects of a 15% depletion in the stratospheric ozone column are about \$2.5 billion in 1982 dollars. Thus, the effects of a doubling of CO_2

imply economic costs two to ten times greater than other environmental stresses that are currently subject to some forms of regulation.

While economic surplus estimates provide a means of comparing climate change effects with other agricultural adjustments, a less abstract policy concern is whether climate change is a food security issue for the United States. The results of these analyses, even in the most extreme case, indicate that the productive capacity of U.S. agriculture will not be reduced to a level that implies major disruptions to the supply of the modeled commodities. U.S. consumers face slightly to moderately higher prices under most analyses, but supplies are adequate to meet current and projected domestic demand. Exports, however, experience major reductions, given the excess demand characteristics of export markets. Almost half of the consumers' surplus losses from climate change in the U.S. fall on foreign consumers. However, because the analyses do not include changes in production in the rest of the world due to climate changes, effects on the U.S. balance of trade are uncertain. While the full welfare effect of U.S. export reductions is unknown, those most likely to be affected are the currently stressed countries of the semiarid tropics, largely in Africa (Mabbutt).

Technology or other assumptions can easily alter these economic estimates. For example, with moderate technological change, or a yield-enhancing effect of CO_2, the productive capacity of U.S. agriculture will likely be greater in seventy-five years than today, even with climate change. This is seen in table 3, where under the more modest GISS climate changes, technology and/or CO_2 direct effects appear capable of partially or totally offsetting adverse climatic effects. For a GFDL-type of climate change, the picture is not so comforting. While technology can potentially offset some of these larger GFDL losses, continued and substantial improvements in yields are required. It should also be noted that the adverse effects of climate change still impose an economic cost in terms of loss of potential productivity (in the absence of climate change).

Table 3. Aggregate Economic Effects of Climate Change on U.S. Agriculture, 1982 dollars

Model/Assumption	Change in Economic Surplus (billions)
GISS	−5.853
GFDL	−33.599
GISS, with technological change[a]	−2.133
GFDL, with technological change[a]	−20.814
GISS, with technological change *and* increased demand[b]	−6.785
GFDL, with technological change *and* increased demand[b]	−44.588
GISS, with direct effects of CO_2[c]	+10.646
GFDL, with direct effects of CO_2[c]	−9.683

[a] Technological change reflects increases in specific crop yields to 2060 equal to the annual rate observed over the 1955–87 time period for those crops.

[b] Increases in demand based on forecast increases in population in the U.S. (42%) and in the world population (114%) to the year 2060.

[c] Direct effects of CO_2 include the potential yield-enhancing effect of CO_2 on crops, combined with the adverse climate effects.

Effects on Regional Production and Irrigated Acreage

For the United States as a whole, both climate model forecasts lead to a slight reduction in a total cropped acreage (2% to 3% in the national assessment). The aggregate numbers, however, mask some potentially large regional adjustments. For example, all analyses show a north or northwest shift in production of major commodities such as wheat, corn, and soybeans. This has implications for regional economies, with likely increased input demands in areas of expanded crop acreage, such as the Northern Plains and corresponding reductions in regions experiencing acreage declines, such as the Southwest and Appalachia. For many rural communities, this may further weaken an economic base already under pressure from long-term structural changes underway in U.S. agriculture.

A related finding concerns changes in the pattern and magnitude of irrigated acreage. Changes in precipitation and temperatures under doubled CO_2 tend to favor irrigated crop production relative to dryland activities (Rosenzweig 1988). Also, rising commodity prices from reductions in total output of most crops enhance the feasibility of irrigation activities, particularly those associated with groundwater use. As a result, irrigated crop acreage increases in most regions. In the aggregate, the increases vary from 5 million (GISS) to 18 million (GFDL) acres. Even allowing for technology changes and the potential yield-enhancing effects of CO_2, increases of at least 2 million acres

are observed under the doubled CO_2 environment. Major increases in irrigated acreage occur in the Northwest and Northern Plains.

If such shifts occur, the western United States appears headed for a larger market share of some commodities. However, even within the seventeen western states, some states lose market share because of adverse climate changes. The Southwest (Arizona, New Mexico, Texas) appears to be the biggest loser. While there will be a slight expansion in irrigated acreage, total cropped acreage declines sharply due to extreme heat and reduced water supplies. Conversely, the Northwest and northern Rockies will gain in total acreage, with modest increases in California.

Environmental Quality Effects

Shifts in crop production and expansion in irrigated acreage imply demands or pressure on environmental and natural resources, including water quantity and quality, wetlands, soil, fish and wildlife, and other resources. For example, a northward shift in corn and soybean production (through the Dakotas to southern Canada) may exacerbate the loss of critical prairie wetlands by making drainage and conversion to crop production more profitable. A westward shift increases wind and water erosion of fragile soils. The substantial (2 to 18 million acres) increase in irrigated acreage suggested in all analyses enhances the likelihood of ground and surface water pollution. Obtaining water to facilitate increased irrigated acreage also implies more and larger reservoirs, which in turn implies greater pressure to develop remaining wild or scenic rivers. Increased competition for remaining streamflows thus seems likely.

Streamflow patterns are expected to change as a result of the diminished importance of snowmelt. As a result, water temperatures are likely to rise. This implies that important cold water species, such as trout, salmon, and steelhead, will be displaced by warm water species. Reservoir fisheries will replace stream fisheries. Forest ecosystems will change, with some coniferous forest species, such as Ponderosa Pine and Douglas fir, being displaced. Wildlife populations will be reduced because of habitat losses and more extreme weather variability. These effects suggest a far reduced set of recreational/environmental assets for future generations. How these changes will affect their welfare is a potentially important research question for resource economists.

Overall, both climate models imply adjustments within agriculture, with GFDL implying some major adjustment problems, particularly for consumers and specific regions, with associated effects on environmental quality. The direction (signs) on these economic changes are generally consistent with qualitative expectations. In addition, however, there are more specific implications for western agriculture and resource use that can also be gleaned from the economic analyses performed here. These are discussed below.

Water Resource Issues: Changing Institutions Versus Engineering Solutions

As the climate assumptions under which existing water resource projects were constructed fail to be realized, water resource managers will be forced to consider mitigation measures. The increased spatial and temporal variability in rainfall and reductions in snowpack predicted by the climate models, coupled with rising commodity prices, will increase pressure for construction of new dams for both flood control and irrigation water storage. While some will urge such engineering solutions, political resistance to new water resource projects is likely to remain high. If so, nonstructural measures, such as water marketing, will become increasingly important.

The California study investigated the effectiveness of voluntary water transfers in alleviating the effects of reduced surface water deliveries. If all publicly provided surface water supplies were sold to the highest bidder, the economic damage to California agriculture and consumers from climate changes would be reduced by approximately 10%. More critically, water marketing facilitates regional adjustments to differential productivity and water supply impacts. As the numbers suggest, however, it is not a panacea. In fact, the San Joaquin Valley, predicted to be disadvantaged by crop productivity impacts from climate change, increasingly depends on groundwater. Current overdraft and groundwater quality problems in the region highlight both the uncertainties and importance of groundwater in dealing with climate change.

A related implication of the climate model hydrology forecasts arises from the possibility that streamflows from the northern Rockies

may increase at the same time that Southwest streamflows decline. This suggests that major river systems that cross state lines, such as the Colorado and Missouri, will be under increased pressure for reallocation between states of origin (e.g., Wyoming, Colorado, and Montana) and downstream users. A large unknown involves the effect of climate change on the urban municipal and industrial demand for water within regions. Forecasts of less water available in the Southwest may well cause increased competition between regions as well as increased diversions of water from irrigation to nonagricultural uses. Existing regional compacts and other institutions may not adequately cover changes in the origin of water within a region.

It should be stressed that much of the expansion in the western United States comes from increased use of groundwater, motivated by higher commodity prices. However, the hydrology of groundwater transport is complex. Even with increased runoff in some areas, the slow rate of groundwater recharge implies that overdrafting will continue or even accelerate in many western regions. The long-term feasibility of groundwater pumping will depend on changes in pumping lifts, energy costs, pumping efficiencies, and so forth.

Other Resource Issues

Climate change will impose some indirect effects on agriculture, particularly in terms of input costs. Perhaps the most important of these will be energy costs. For example, as the adverse consequences of climate change become a reality, control measures on fossil fuel combustion are likely. Current technology for CO_2 emissions reductions on fossil fuel combustion is costly. Construction of nuclear power plants is also costly. As a result, real per unit costs of electricity will rise. This implies that the feasibility of expanded or even current irrigation will be dependent on increases in real commodity prices sufficient to offset energy cost increases.

Agriculture itself generates various greenhouse gases. Methane from flooded rice fields and livestock, nitrous oxide from fertilizer use, carbon dioxide from fossil fuel use, and CFCs used in food processing are all greenhouse gases. Policy measures to reduce CFC use are already in place. Control measures for other greenhouse gases would likely include agricultural sources. Given our past history of environmental regulation, such controls could generate additional financial stress for farm firms and exaggerate spatial adjustments. Additionally, controls on fertilizer would occur exactly when productivity increasing inputs would be in high demand.

Finally, agriculture may also be asked to contribute to solving the problem. Some scientists have proposed expanded forest regions as a method of removing carbon dioxide from the atmosphere (Woodwell). The potential for an expanded Conservation Reserve Program to manage climate changes deserves analysis.

Conclusions

The analyses summarized in this paper suggest that rapid changes in climate caused by CO_2 and other atmospheric trace gases have the potential to change the structure of U.S. agriculture, particularly at the regional level. While some of the implications of this change are as speculative as the underlying assumptions, most seem plausible if one accepts the general validity of the climate change forecasts and the inevitability of further increases in atmospheric CO_2. At present, there is little evidence to contradict the CO_2 and climate change trends used here.

In summary, a couple of points seem important. First, economic processes have the potential to mitigate for the direct effects of climate change on agricultural production and consumption. In fact, such potential adjustments are likely understated in the economic models used here, given the long time horizons involved. While the adequacy of food and fiber production may not be an issue, it seems probable that the conflict between those adjustments that fill the stomach and those which nurture the human psyche will intensify. Thus, a more rapid loss of environmental and other nonmarket assets and consumption opportunities seems likely under the climate projections. This implies that future generations will be the real losers. Second, most of the implications drawn here do not open vast new areas for economic research. Rather, they suggest a continuation (and perhaps renewal) of much of the resources-oriented research performed by agricultural economists over the last several decades. The challenge will be to provide better information to meet these new resource

allocation problems; the costs of being wrong will be much greater under the harsher environmental conditions portrayed here.

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